CERTIFICATE OF TRANSLATION

I, Po-Hung Chen of TOP TEAM INTERNATIONAL PATENT & TRADEMARK OFFICE located at 3rd Fl., No. 279, Sec. 4, Hsin-Yi Rd., Taipei, Taiwan, R.O.C, hereby declare that I am the translator of the attached Taiwan priority document no. 91133808, filed on November 20, 2002, and certify that the following is a true translation of the document to the best of my knowledge and belief.

Signature of Translator Po hung Chen
Po-Hung Chen

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TIUTLE : METHOD AND APPARATUS FOR I/Q IMBALANCE ESTIMATION

Abstract :

A method and apparatus for estimating and compensating a I/Q imbalance. The method comprises transmitting a first signal modulated by a first and a second modulated carrier through a modulation path at a transmitter, receiving the first signal demodulated by a first and a second demodulated carrier respectively through a first and a second demodulation path at a receiver, transmitting a second signal modulated by the first and the second modulated carrier through the modulation path at the transmitter, receiving the second signal demodulated by the first and the second demodulated carrier respectively through the first and second demodulation path at the receiver, deriving the I/Q imbalance parameter of the receiver according to the first and the second signal, transmitting a third signal modulated by a first modulated carrier through a first modulation path, transmitting a fourth signal modulated by a second modulated carrier through a second modulation path, receiving the third signal demodulated by a first demodulated carrier through a demodulation path, receiving the fourth signal demodulated by a second demodulated carrier through the demodulation path, and deriving an I/Q imbalance of the transmitter according to the demodulated third and the fourth signals. The first and second signals are symmetrical in frequency domain and the third signal and the fourth signal are symmetrical in frequency domain.

Representative Figure：

Fig. 2

Representative Figure Symbol：

10: switch;

21、22、23、24: low-pass filter

100、102: A/D converter;

200、202: D/A converter;

150: receiving compensating matrix;

250: receiving compensating matrix;

300: estimator;

350: carrier recovery circuit

352: AGC circuit;

400: signal generator;

500: FFT;

550: IFFT;

MIX1 ~ MIX4: mixer;

MUX1～MUX8: multiplexer

Field of the Invention :

The present invention relates to a method and apparatus for signal estimation and compensation, and particularly to a method and apparatus for I/Q imbalance compensation and estimation.

Description of the Prior Art :

In a quadrature modulation/demodulation system, the real and imaginary parts of a baseband time-domain complex signal are transmitted simultaneously from the transmitter. They are carried on two orthogonal carriers (sine and cosine waves), respectively. The receiver uses the same orthogonal carriers to demodulate the received signal and derives the original real and imaginary part of the baseband complex signal. The modulation/demodulation of the real part of the baseband complex signal is called in-phase (I) modulation/demodulation while that of the imaginary part is called quadrature-phase (Q) modulation/demodulation.

In practice, there is always a mismatch between I and Q modulation/demodulation, that is to say, there are always gain and phase offset in the I/Q modulated (or demodulated) signals. This is the I/Q imbalance known in the art.

FIG. 1A and 1B are diagrams respectively showing the I/Q imbalance at the receiver and transmitter. As shown in the figures, crosstalk occurs due to I/Q imbalance, which can not be eliminated even with the ACG (automatic gain

control) and carrier recovery circuitry. Further, ICI(inter carrier interference) also occurs for OFDM signals.

Conventionally, the solution to the previous problem is a circuitry system carefully designed to alleviate the I/Q imbalance. However, in an OFDM system, ICI is easily caused by I/Q imbalance because multi-carriers are used for high-speed transmission. This raises a need for a correction circuitry system, such as an equalizer or ICI eliminator. Even worse, in an OFDM system used for wireless LAN using burst mode transmission, the equalizer or ICI eliminator cannot achieve adequate compensation of I/Q imbalance.

SUMMARY OF THE INVENTION :

A method and apparatus for estimating and compensating a I/Q imbalance is provided. The method comprises transmitting a first signal modulated by a first and a second modulated carrier through a modulation path at a transmitter, receiving the first signal demodulated by a first and a second demodulated carrier respectively through a first and a second demodulation path at a receiver, transmitting a second signal modulated by the first and the second modulated carrier through the modulation path at the transmitter, receiving the second signal demodulated by the first and the second demodulated carrier respectively through the first and second demodulation path at the receiver, deriving the I/Q imbalance parameter of the receiver according

to the first and the second signal, transmitting a third signal modulated by a first modulated carrier through a first modulation path, transmitting a fourth signal modulated by a second modulated carrier through a second modulation path, receiving the third signal demodulated by a first demodulated carrier through a demodulation path, receiving the fourth signal demodulated by a second demodulated carrier through the demodulation path, and deriving an I/Q imbalance of the transmitter according to the demodulated third and the fourth signals. The first and second signals are symmetrical in frequency domain and the third signal and the fourth signal are symmetrical in frequency domain.

DETAILED DESCRIPTION OF THE INVENTION

In the following embodiment of the invention, since there is usually no rapid variation in I/Q imbalance, the imbalance is estimated and corrected based upon the characters of the OFDM transmitter or receiver when the system being started or idled.

As shown in FIG. 1A, the I/Q imbalance at the receiver is expressed as a 2*2 matrix function composed of four parameters $\alpha_r\cos\theta_r$, $\alpha_r\sin\theta_r$, $\beta_r\cos\phi_r$ and $\beta_r\sin\phi_r$, where α_r and β_r are gain offsets while θ_r and ϕ_r are phase offsets of the I and Q demodulation path in the receiver. The four parameters of the receiver I/Q imbalance matrix can be estimated by generating a signal with a specific frequency before inverse fast Fourier

Transform (IFFT). The signal with the specific frequency is transmitted in the from of a time-domain signal with either imaginary or real part power. Thus, the signal is transmitted through only one of paths of the transmitter. The gain and phase offsets of the signal can be compensated by the automatic gain control and carrier recovery circuit in the receiver. In this manner, the parameters $\alpha_r\cos\theta_r$ and $\beta_r\sin\theta_r$ are derived through transmitting a time-domain real part power signal while the parameters $\alpha_r\sin\theta_r$ and $\beta_r\cos\theta_r$ are derived through transmitting from a time-domain imaginary part power signal.

As shown in FIG. 1B, the I/Q imbalance at the transmitter is expressed as a 2*2 matrix function composed of four parameters $\alpha_t\cos\theta_t$, $\alpha_t\sin\theta_t$, $\beta_t\cos\phi_t$ and $\beta_t\sin\phi_t$, where α_t and β_t are gain offsets while θ_t and ϕ_t are phase offsets of the I and Q modulation paths in the transmitter. The four parameters of the transmitter I/Q imbalance matrix can be estimated by transmitting two signals, each of which includes the power of the real and imaginary part in time domain, in two different periods and demodulating them at the receiver through the same demodulation path. In the demodulation of each signal received by the receiver, two orthogonal carriers are used to respectively demodulate the real and imaginary parts of time-domain signals from the received signal. The parameters $\alpha_t\cos\theta_t$ and $\beta_t\sin\theta_t$ are derived from the real part of two receiving signals while the parameters $\alpha_r\sin\theta_r$ and $\beta_r\cos\theta_r$ are derived from the imaginary part of two receiving signals. The

estimated signal may include the gain and phase offsets. However, it can be compensated by channel effect processing.

Accordingly, the I/Q imbalance estimation is based on transmitting/receiving signal through one single modulation/demodulation path to estimate the I/Q imbalance parameters. The baseband signal for the imbalance estimation should be properly selected to simplify the estimation process.

FIG. 2 is a diagram showing an apparatus for estimation and compensation of I/Q imbalance. The frequency-domain signal generator 400 transmits a signal to the IFFT processor 550 converting the signal from frequency domain to time domain. The time-domain signal is sent to the transmitting compensating matrix circuit 250. The I modulation path of the transmitter includes a multiplexer MUX1, a D/A converter 200, a low-pass filter 22, and a mixer MIX1. The Q modulation path of the transmitter includes multiplexers MUX2, MUX3, MUX4 ,and MUX5, a D/A converter 202, low-pass filter 24, and mixer MIX2. The multiplexer MUX1 switch signals in the I modulation path while the multiplexers MUX2 and MUX3 switches signals in the Q modulation path. The multiplexers MUX4 and MUX5 select carriers for the I and Q modulation paths.

The I demodulation path of the receiver includes a mixer MIX3, a low-pass filter 21, an A/D converter 100 and a multiplexer MUX6. The Q demodulation path of the receiver includes a mixer MIX4, multiplexers MUX 7 and MUX8, a low-pass filter 23, and an A/D converter 102. The signals

going through the I and Q demodulation paths are sent to the receiving compensating matrix circuit 150 and then processed by the AGC circuit 352 and carrier recovery circuit 350. The FFT processor 500 converts the signal from the carrier recovery circuit 350 to a frequency-domain signal. The estimator 300 generates the parameters for the transmitting compensating matrix circuit 150 and receiving compensating matrix circuit 250. The multiplexer MUX6 switches signals in the I demodulation path while the multiplexers MUX7 and MUX8 select carriers for the I and Q demodulation paths of the receiver.

The A/D converters 100 and 102 are followed by the receiving compensating matrix circuit 150 for compensation of the receiver I/Q imbalance. Similarly, the transmitting compensating matrix circuit 250 is preceded by the transmitter for compensation of the transmitter I/Q imbalance.

As shown in FIG. 1A, the receiver I/Q imbalance is expressed as:

$$\begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix} = \begin{bmatrix} \alpha_r \cos\theta_r & \alpha_r \sin\theta_r \\ -\beta_r \sin\phi_r & \beta_r \cos\phi_r \end{bmatrix} \bullet \begin{bmatrix} x_i(i) \\ x_q(t) \end{bmatrix} \qquad (1)$$

Thus, by deriving the four parameters $\alpha_r\cos\theta_r$, $\alpha_r\sin\theta_r$, $\beta_r\cos\phi_r$ and $\beta_r\sin\phi_r$, the compensation done by the receiving compensating matrix circuit 150 turns to be a matrix function:

$$\begin{bmatrix} \beta_r \cos\phi_r & -\alpha_r \sin\theta_r \\ \beta_r \sin\phi_r & \alpha_r \cos\theta_r \end{bmatrix} \qquad (2)$$

The received signal is then expressed as:

$$\begin{bmatrix} r_i(t) \\ r_q(t) \end{bmatrix} = \begin{bmatrix} \beta_r \cos\phi_r & -\alpha_r \sin\theta_r \\ \beta_r \sin\phi_r & \alpha_r \cos\theta_r \end{bmatrix} \bullet \begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix} \qquad (3)$$

$$= \begin{bmatrix} \beta_r \cos\phi_r & -\alpha_r \sin\theta_r \\ \beta_r \sin\phi_r & \alpha_r \cos\theta_r \end{bmatrix} \bullet \begin{bmatrix} \alpha_r \cos\theta_r & \alpha_r \sin\theta_r \\ -\beta_r \sin\phi_r & \beta_r \cos\phi_r \end{bmatrix} \bullet \begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix}$$

$$= (\alpha_r \cdot \beta_r \cdot \cos(\theta_r - \phi_r)) \bullet \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} x_i(t) \\ x_q(t) \end{bmatrix} \qquad (4)$$

$[\alpha_r \,.\, \beta_r \,.\, \cos(\theta_r - \phi_r)]$ is the residual gain offset which is further compensated by the AGC circuit. During the estimation of the I/Q imbalance, the phase difference between the transmitted and received signal has no impact on the compensation since it is eliminated by the carrier recovery circuit.

Similarly, by deriving the four parameters $\alpha_t\cos\theta_t$, $\alpha_t\sin\theta_t$, $\beta_t\cos\phi_t$ and $\beta_t\sin\phi_t$, the compensation of the transmitter I/Q imbalance done by the transmitting compensating matrix circuit 250 turns to be a matrix function:

$$\begin{bmatrix} \beta_t \cos\phi_t & \beta_t \sin\phi_t \\ -\alpha_t \sin\theta_t & \alpha_t \cos\theta_t \end{bmatrix} \qquad (5)$$

when the receiver I/Q imbalance is cancelled, the compensated signal is then expressed as:

$$\begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix} = \begin{bmatrix} \alpha_t \cos\theta_t & -\beta_t \sin\phi_t \\ \alpha_t \sin\theta_t & \beta_t \cos\phi_t \end{bmatrix} \bullet \begin{bmatrix} v_i(t) \\ v_q(t) \end{bmatrix} \qquad (6)$$

$$= \begin{bmatrix} \alpha_t \cos\theta_t & -\beta_t \sin\phi_t \\ \alpha_t \sin\theta_t & \beta_t \cos\phi_t \end{bmatrix} \bullet \begin{bmatrix} \beta_t \cos\phi_t & \beta_t \sin\phi_t \\ -\alpha_t \sin\theta_t & \alpha_t \cos\theta_t \end{bmatrix} \bullet \begin{bmatrix} x_i(t) \\ x_q(t) \end{bmatrix}$$

$$= (\alpha_t \beta_t \cdot \cos(\theta_t - \phi_t)) \bullet \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} x_i(t) \\ x_q(t) \end{bmatrix} \qquad (7)$$

For estimating these I/Q imbalance parameters, using the effect of I/Q

imbalance to OFDM, transmitting a special signal from the baseband, these I/Q imbalance parameters can be identified by the correlation.

When a signal x (x_i+jx_q) is converted to a signal y (y_i+jy_q) by a function:

$$\begin{bmatrix} y_i \\ y_q \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \bullet \begin{bmatrix} x_i \\ x_q \end{bmatrix} \qquad (8)$$

the signal y is a linear combination of x and x*, and can be expressed as:

$$y = C \cdot x + D \cdot x^* \qquad (9)$$

Where

$C=c_i+jc_q$; $D=d_i+jd_q$

$c_i+d_i=A_{11}$; $-c_q+d_q=A_{12}$; $c_q+d_q=A_{21}$; $c_i-d_i=A_{22}$

If the signal x(t) is a complex OFDM signal, then

$$x(t) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}} a_k \cdot e^{j \cdot 2\pi f_s t} \qquad (10)$$

$$y(t) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}} (C \cdot a_k + D \cdot a_{-k}) \cdot e^{j \cdot 2\pi f_s t} \qquad (11)$$

$$= \sum_{k=-\frac{N}{2}}^{\frac{N}{2}} \hat{a}_k \cdot e^{j \cdot 2\pi f_s t} \qquad (12)$$

where $\hat{a}_k$ can be expressed by the following matrix form:

$$\begin{bmatrix} \hat{a}_{k,i} \\ \hat{a}_{k,q} \end{bmatrix} = \begin{bmatrix} c_i & -c_q \\ c_q & c_i \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} + \begin{bmatrix} d_i & d_q \\ d_q & -d_i \end{bmatrix} \bullet \begin{bmatrix} a_{-k,i} \\ a_{-k,q} \end{bmatrix} \qquad (13)$$

where a_k is the frequency-domain signal in k^{th} sub-channel, $a_{k,i}$ is the real part of a_k and $a_{k,q}$ is the imaginary part of a_k.

Thus, the parameters used for compensating the I/Q imbalance can be derived by the equation (13) and characteristics of the OFDM signal. In order

to avoid the impact of the transmitter I/Q imbalance adding to the receiver, only one single demodulation path (either real-part modulation path I_tx or imaginary-part modulation path Q_tx of the transmitting node) is used during the estimation of the receiver I/Q imbalance.

When $a_{k,i}= a_{-k,i}$(symmetric) and $a_{k,q}=-a_{-k,q}$(anti-symmetric), the real part frequency-domain signal being symmetric and the imaginary part frequency-domain signal being anti-symmetric, only a real-part time-domain OFDM signal is transmitted. Transmitting this signal through only one of the I and Q modulation paths. In this embodiment, the signal is transmitted through the Q_tx modulation path and carried by a cosine ($\cos(\omega_c t)$) carrier wave. The received signal is received through the real demodulating path I_rx and the imaginary demodulating path Q_rx of the receiver. Demodulating the received signal by the FFT processor 500, $\hat{a}_k$ is:

$$\begin{bmatrix} \hat{a}_{k,i} \\ \hat{a}_{k,q} \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix}$$

$$= \begin{bmatrix} c_i + d_i & -(c_q + d_q) \\ c_q + d_q & c_i + d_i \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (14)$$

$$= \begin{bmatrix} \alpha_r \cos\theta_r & \beta_r \sin\phi_r \\ -\beta_r \sin\phi_r & \alpha_r \cos\theta_r \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (15)$$

When $a_{k,i}=-a_{-k,i}$ (anti-symmetric) and $a_{k,q}= a_{-k,q}$ (symmetric), the real part frequency-domain signal being anti-symmetric and the imaginary part

frequency-domain signal being symmetric, only an imaginary-part time-domain OFDM signal is transmitted . Transmitting this signal through only one of the I and Q modulation paths. In this embodiment, the signal is transmitted through the Q_tx modulation path and carried by a sine ($-\sin(\omega_c t)$) carrier wave. The received signal is received through the real path I_rx and the imaginary path Q_rx ot the receiver . Demodulating the received signal by the FFT processor 500, $\hat{a}_k$ is turned to be:

$$\begin{bmatrix} \hat{a}_{k,i} \\ \hat{a}_{k,q} \end{bmatrix} = \begin{bmatrix} c_i - d_i & -(c_q - d_q) \\ c_q - d_q & c_i - d_i \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (16)$$

$$= \begin{bmatrix} \beta_r \cos\phi_r & \alpha_r \sin\theta_r \\ -\alpha_r \sin\theta_r & \beta_r \cos\phi_r \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (17)$$

The following is an estimation method of the IQ imbalance parameters of a receiver:

Thus, from the equation (15), if $a_{k,i}=a_{k,q}=1$, and $a_{-k,i}= a_{k,i}$ and $a_{-k,q}=-a_{k,q}$, then

$$\begin{aligned} \hat{a}_{k,i} &= \alpha_r \cos\theta_r + \beta_r \sin\phi_r \\ \hat{a}_{k,q} &= -\beta_r \sin\phi_r + \alpha_r \cos\theta_r \end{aligned} \qquad (18)$$

$$\therefore \quad \alpha_r \cos\theta_r = \frac{\hat{a}_{k,i} + \hat{a}_{k,q}}{2} \quad ; \quad \beta_r \sin\phi_r = \frac{\hat{a}_{k,i} - \hat{a}_{k,q}}{2} \qquad (19)$$

From the equation (17), if $a_{k,i}=a_{k,q}=1$, and $a_{-k,i}=-a_{k,i}$ and $a_{-k,q}=a_{k,q}$, then

$$\begin{aligned} \hat{a}_{k,i} &= \alpha_r \sin\theta_r + \beta_r \cos\phi_r \\ \hat{a}_{k,q} &= \beta_r \cos\phi_r - \alpha_r \sin\theta_r \end{aligned} \qquad (20)$$

$$\therefore \quad \alpha_r \sin\theta_r = \frac{\hat{a}_{k,i} - \hat{a}_{k,q}}{2} \quad ; \quad \beta_r \cos\phi_r = \frac{\hat{a}_{k,i} + \hat{a}_{k,q}}{2} \qquad (21)$$

Alternatively, the parameters $\alpha_r\cos\theta_r$, $\alpha_r\sin\theta_r$, $\beta_r\cos\phi_r$ and $\beta_r\sin\phi_r$ for the receiver I/Q imbalance compensation may also be estimated by transmitting predetermined and independent frequency-domain signals wherein $a_{k,i}=a_{k,q}=\pm1$ and using a parameter identification structure and method of a correlator at the receiver. FIG. 3 is a block diagram showing a simplified parameter identification system of a parameter estimator. The values of M11, M12, M21 and M22 are $\alpha_r\cos\theta_r$, $\alpha_r\sin\theta_r$, $\beta_r\sin\phi_r$ and $\beta_r\cos\phi_r$ respectively, and are sent to the receiving compensating matrix circuit 150 for solving the receiver I/Q imbalance problem. N is the number of the transmitted symbols. The multipliers shown in FIG. 3 may be replaced by inverters or shift registers. This simplified parameter identification system may apply to a communication (transmitter/receiver) system having an RF (Radio Frequency) circuit without DC bias for transmitting the continuous deterministic signals.

The transmitter I/Q imbalance is estimated by transmitting two OFDM signals with $a_{k,i}=a_{-k,i}$ and $a_{k,q}=a_{-k,q}$, the real part frequency-domain signal and the imaginary frequency-domain signal being symmetric, through the I_tx and Q_tx modulation path respectively so that

$$\begin{bmatrix} \hat{a}_{k,i} \\ \hat{a}_{k,q} \end{bmatrix} = \begin{bmatrix} c_i + d_i & -c_q + d_q \\ c_q + d_q & c_i - d_i \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (22)$$

$$=\begin{bmatrix}\alpha_t\cos\theta_t & -\beta_t\sin\phi_t\\ \alpha_t\sin\theta_t & \beta_t\cos\phi_t\end{bmatrix}\bullet\begin{bmatrix}a_{k,i}\\ a_{k,q}\end{bmatrix} \qquad (23)$$

In order to avoid the impact of receiver I/Q imbalance, only one single demodulation path (either real-part modulation path I_rx or imaginary-part modulation path Q_tx of the receiving node) is used during the estimation of transmitter I/Q imbalance. The real-part of the time-domain signal is demodulated alone using a cosine ($\cos(\omega_c t)$) carrier wave and the imaginary-part time-domain signal is demodulated alone using a sine ($\sin(\omega_c t)$) carrier wave in different time period.

When $a_{k,i}= a_{-k,i}$ (symmetric) and $a_{k,q}= a_{-k,q}$ (symmetric), that is both the real-part and the imaginary-part frequency domain signal are symmetric, the time-domain OFDM signal is transmitted through the Q demodulation path Q_rx and is demodulated using a cosine ($\cos(\omega_c t)$) carrier wave to demodulate the real-part time-domain signal. Then the real-part time-domain signal is converted to frequency domain by the FFT processor 500 so that

$$\begin{bmatrix}\hat{a}_{k,i}\\ \hat{a}_{k,q}\end{bmatrix}=\begin{bmatrix}c_i+d_i & -c_q+d_q\\ 0 & 0\end{bmatrix}\bullet\begin{bmatrix}a_{k,i}\\ a_{k,q}\end{bmatrix} \qquad (24)$$

$$=\begin{bmatrix}\alpha_t\cos\theta_t & -\beta_t\sin\phi_t\\ 0 & 0\end{bmatrix}\bullet\begin{bmatrix}a_{k,i}\\ a_{k,q}\end{bmatrix} \qquad (25)$$

If the time-domain signal is transmitted through the imaginary-part demodulation path Q_rx and is demodulated using a sine ($\sin(\omega_c t)$) carrier wave to demodulate the imaginary-part time-domain signal. Then the imaginary-part time-domain signal is converted to frequency domain by the FFT processor 500 so that

$$\begin{bmatrix} \hat{a}_{k,i} \\ \hat{a}_{k,q} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ c_q + d_q & c_i - d_i \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (26)$$

$$= \begin{bmatrix} 0 & 0 \\ \alpha_t \sin\theta_t & \beta_t \cos\phi_t \end{bmatrix} \bullet \begin{bmatrix} a_{k,i} \\ a_{k,q} \end{bmatrix} \qquad (27)$$

By using the system and method disclosed above with the OFDM signals that $a_{k,i}= a_{-k,i}$ and $a_{k,q}= a_{-k,q}$, the parameters of $\alpha_t\cos\theta_t$, $\alpha_t\sin\theta_t$, $\beta_t\sin\phi_t$ and $\beta_t\cos\phi_t$ can be determined respectively for transmitting compensating matrix circuit 250 to solve the transmitter I/Q imbalance problem. Alternatively, the parameters for compensation of the transmitter I/Q imbalance may also be derived by the estimator shown in FIG. 3, wherein the values of M_{11}, M_{12}, M_{21} and M_{22} are $\alpha_t\cos\theta_t$, $-\beta_t\sin\phi_t$, $\alpha_t\sin\theta_t$ and $\beta_t\cos\phi_t$ respectively. These parameters are for use by the transmitting compensation matrix circuit 250.

FIG. 4A and 4B respectively show constellations of an I/Q imbalanced modulation before and after the compensation.

It should be noted that the relation between the $a_{k,i}$, $a_{-k,i}$, $a_{k,q}$ and $a_{-k,q}$ is not necessarily limited to that described previously. The receiver I/Q imbalance may be estimated only by transmitting the signal through the same modulation path and the transmitter I/Q imbalance may be estimated only by receiving the signal through the same demodulation path. However, this increases difficulty in baseband signal processing.

The present invention takes advantage of the modulation/demodulation

characteristics of OFDM signals to estimate the receiver and transmitter I/Q imbalance, and further uses a specifically predetermined signal to simplify the estimation to get the receiving compensating matrix and the transmitting compensating matrix.

The foregoing description of the preferred embodiments of this invention has been presented for purposes of illustration and description. Obvious modifications or variations are possible in light of the above teaching. The embodiments were chosen and described to provide the best illustration of the principles of this invention and its practical application to thereby enable those skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the present invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

BRIEF DESCRIPTION OF THE DRAWINGS :

FIG. 1A is a diagram showing the I/Q imbalance at the receiver.

FIG. 1B is a diagram showing the I/Q imbalance at the transmitter.

FIG. 2 is a diagram showing an apparatus for estimation and compensation of I/Q imbalance.

FIG. 3 is a block diagram showing an estimator used in the apparatus for estimation and compensation of I/Q imbalance.

FIG. 4A shows constellations of an imbalanced modulation before the compensation.

FIG. 4B shows constellations of an imbalanced modulation after the compensation.

Symbol :

1: ideal real part modulation path at transmitter

2: ideal imaginary part modulation path at transmitter

3: non-ideal real part demodulation path at receiver

4: non-ideal imaginary part demodulation path at receiver

5: non-ideal real part modulation path at transmitter

6: non-ideal imaginary part modulation path at transmitter

7: ideal real part demodulation path at receiver

8: ideal imaginary part demodulation path at transmitter

10: switch

21、22、23、24: low-pass filter

100、102: A/D converter

200、202: D/A converter

150: receiving compensating matrix

250: receiving compensating matrix

300: estimator

350: carrier recovery circuit

352: AGC circuit

400: signal generator

500: FFT

550: IFFT

MIX1 ~ MIX4: mixer

MUX1～MUX8: multiplexer

What is claimed is:

1. A method for estimating a I/Q imbalance parameter of a receiver, comprising the steps of:

transmitting a first signal modulated by a first and a second modulated carrier through a modulation path at a transmitter;

receiving the first signal demodulated by a first and a second demodulated carrier respectively through a first and a second demodulation path at a receiver;

transmitting a second signal modulated by the first and the second modulated carrier through the modulation path at the transmitter;

receiving the second signal demodulated by the first and the second demodulated carrier respectively through the first and second demodulation path at the receiver; and

deriving the I/Q imbalance parameter of the receiver according to the first and the second signal;

wherein the first and second signal are symmetrical in frequency domain.

2. The method of claim 1, wherein the first modulated carrier is a real-value modulated carrier, the second modulated carrier is an imaginary-value modulated carrier, the modulation path is one of I_channel and Q_channel, the first demodulation path is a

I_channel, the second demodulation path is a Q_channel, the first demodulated carrier is a real-value demodulated carrier,and the second demodulated carrier is an imaginary-value demodulated carrier.

3. The method of claim 1, wherein the real part of the first signal is symmetric while the imaginary part of the first signal is anti-symmetric in frequency domain.

4. The method of claim 3, wherein amplitudes of the real and imaginary part of the first signal are the same in frequency domain.

5. The method of claim 1, wherein the real part of the second signal is anti-symmetric while the imaginary part of the second signal is symmetric in frequency domain.

6. The method of claim 5, wherein amplitudes of the real and imaginary part of the second signal are the same in frequency domain.

7. The method of claim 1, wherein the first and second signals are predetermined signals.

8. The method of claim 7, wherein the amplitude of the real and the imaginary part of the first and second signals are either +1 or -1.

9. The method of claim 1, wherein the first and second signals are independent each other.

10. A method for transmitter I/Q imbalance estimation comprising the steps of:

transmitting a third signal modulated by a first modulated carrier through a first modulation path;

transmitting a fourth signal modulated by a second modulated carrier through a second modulation path, wherein the third signal and the fourth signal are symmetrical in frequency domain;

receiving the third signal demodulated by a first demodulated carrier through a demodulation path;

receiving the fourth signal demodulated by a second demodulated carrier through the demodulation path; and

deriving an I/Q imbalance of the transmitter according to the demodulated third and the fourth signals.

11. The method of claim 10, wherein the first modulation path is a I_channel, the second modulation path is a Q_channel, the first modulated carrier is a real-value modulated carrier, the second modulated carrier is an imaginary-value modulated carrier, the first demodulated carrier is a real-value demodulated carrier, the second demodulated carrier is an imaginary-value demodulated carrier, and the demodulation path is one of I_channel and Q_channel.

12. The method of claim 10, wherein the real and the imaginary part of the third and the fourth signals are symmetric in frequency domain.

13. The method of claim 12, wherein amplitudes of the real and imaginary part of the third and the fourth signals are the same in frequency domain.

14. A method for estimating a I/Q imbalance parameter of a receiver, comprising the steps of:

transmitting a first signal modulated by a first and a second modulated carrier through a modulation path at a transmitter;

receiving the first signal demodulated by a first and a second demodulated carrier respectively through a first and a second demodulation path at a receiver;

transmitting a second signal modulated by the first and the second modulated carrier through the modulation path at the transmitter;

receiving the second signal demodulated by the first and the second demodulated carrier respectively through the first and second demodulation path at the receiver;

deriving the I/Q imbalance parameter of the receiver according to the first and the second signal;

transmitting a third signal modulated by a first modulated carrier through a first modulation path;

transmitting a fourth signal modulated by a second modulated carrier through a second modulation path;

receiving the third signal demodulated by a first demodulated carrier through a demodulation path;

receiving the fourth signal demodulated by a second demodulated carrier through the demodulation path; and

deriving an I/Q imbalance of the transmitter according to the demodulated third and the fourth signals,

wherein the first and second signal are symmetrical in frequency domain and the third signal and the fourth signal are symmetrical in frequency domain.

15. The method of claim 14, wherein the first modulation path is a I_channel, the second modulation path is a Q_channel, the first modulated carrier is a real-value modulated carrier, the second modulated carrier is an imaginary-value modulated carrier, and the demodulation path is one of I_channel and Q_channel.

16. The method of claim 14, wherein the first demodulation path is a I_channel, the second demodulation path is a Q_channel, the first demodulated carrier is a real-value demodulated carrier, the second demodulated carrier is an imaginary-value demodulated carrier, and the demodulation path is one of I_channel and Q_channel.

17. The method of claim 14, wherein the real part of the first signal is symmetric while the imaginary part of the first signal is anti-symmetric in frequency domain.

18. The method of claim 17, wherein amplitudes of the real and imaginary part of the first signal are the same in frequency domain.

19. The method of claim 14, wherein the real part of the second signal is anti-symmetric while the imaginary part of the second signal is symmetric in frequency domain.

20. The method of claim 19, wherein amplitudes of the real and imaginary part of the second signal are the same in frequency domain.

21. The method of claim 14, wherein the first and second signals are predetermined signals.

22. The method of claim 21, wherein the amplitude of the real and the imaginary part of the first and second signals are either +1 or -1.

23. The method of claim 21, wherein the first and second signals are independent each other.

24. The method of claim 14, wherein the real and the imaginary part of the third and the fourth signal are symmetric in frequency domain.

25. The method of claim 24, wherein amplitudes of the real and imaginary part of the third and the fourth signal are the same in frequency domain.

26. An apparatus for estimation of transmitter I/Q imbalance in a communication system, the communication system comprising a receiver demodulation device, the apparatus comprising:

a signal generator for generating a first and a second signals, wherein the first and the second signals are symmetrical in frequency domain;

a transmitter for transmitting the first signal modulated by a first modulated signal and the second signal modulated by a second modulated carrier through a first modulation path and a second modulation path; and

an estimator for deriving an I/Q imbalance parameter of the transmitter according to the first signal and the second signal received by the receiver demodulation device.

27. The apparatus of claim 26, wherein the signal generator further comprises an IFFT processor.

28. The apparatus of claim 26, wherein the real and the imaginary part of the first and the second signal are symmetric in frequency domain.

29. The apparatus of claim 28, wherein amplitudes of the real and the imaginary part of the first and the second signal are the same in frequency domain.

30. An apparatus for estimation of receiver I/Q imbalance in a communication system, the communication system comprising a transmitter, the transmitter comprising a signal generator, the signal generator for generating a first and a second signal, the transmitter for transmitting the first signal modulated by a first modulated carrier and the second signal modulated by a second modulated carrier, wherein the first and the second signals are transmitted through a I_channel or a Q_channel, comprising:

a receiver for receiving the first signal demodulated by a first demodulated carrier through a I_channel and demodulated by a second demodulated carrier through a Q_channel, and receiving a second signal demodulated by a first demodulated carrier through a I_channel and demodulated by a second demodulated carrier through a Q_channel; and

an estimator for deriving an I/Q imbalance parameter of the receiver from the first and second signals received by the receiver and the first and second signals transmitted by the transmitter.

31. The apparatus of claim 30, further comprises an IFFT processor.

32. The apparatus of claim 30, wherein the real part of the first signal is symmetric while the imaginary part of the first signal is anti-symmetric in frequency domain.

33. The apparatus of claim 32 wherein amplitudes of the real and imaginary part of the first signal are the same in frequency domain.

34. The apparatus of claim 30, wherein the real part of the second signal is anti-symmetric while the imaginary part of the second signal is symmetric in frequency domain.

35. The apparatus of claim 34, wherein amplitudes of the real and imaginary part of the secondsignal are the same in frequency domain.

36. The apparatus of claim 30, wherein the first and second signals are predetermined signals.

37. The apparatus of claim 36, wherein the amplitude of the real and the imaginary part of the first and second signals are either +1 or -1.

38. The apparatus of claim 36, wherein the first and second signals are independent each other.

39. An apparatus for compensating I/Q imbalance, comprising:

a transmitter, comprising:

an IFFT converting a frequency-domain transmitting signal into a time-domain transmitting signal;

a transmitting compensating matrix receiving the time-domain transmitting signal and outputting a transmitting compensating signal; and

a D\A converter receiving the compensating signal and outputting a transmitting analog signal;

and

a receiver, comprising:

an A\D converter receiving the transmitting analog signal and outputting a digital signal;

a receiving compensating matrix receiving the digital signal and outputting a receiving compensating signal; and

a FFT receiving the receiving compensating signal and outputting a frequency-domain receiving signal,

wherein the transmitting compensating matrix and the receiving compensating matrix are 2*2 matrixes,

wherein values of the transmitting compensating matrix and the receiving compensating matrix are derived by the transmitter transmitting predetermined signals and the receiver receiving the predetermined signal.

40. The apparatus of claim 39, wherein the predetermined signals comprise a first signal and a second signal and the first and second signals are symmetric in frequency.

41. The apparatus of claim 40, wherein the real part of the first signal is symmetric while the imaginary part of the first signal is anti-symmetric in frequency domain.

42. The apparatus of claim 41, wherein amplitudes of the real and imaginary part of the first signal are the same in frequency domain.

43. The apparatus of claim 40, wherein the real part of the second signal is anti-symmetric while the imaginary part of the second signal is symmetric in frequency domain.

44. The apparatus of claim 43, wherein amplitudes of the real and imaginary part of the second signal are the same in frequency domain.

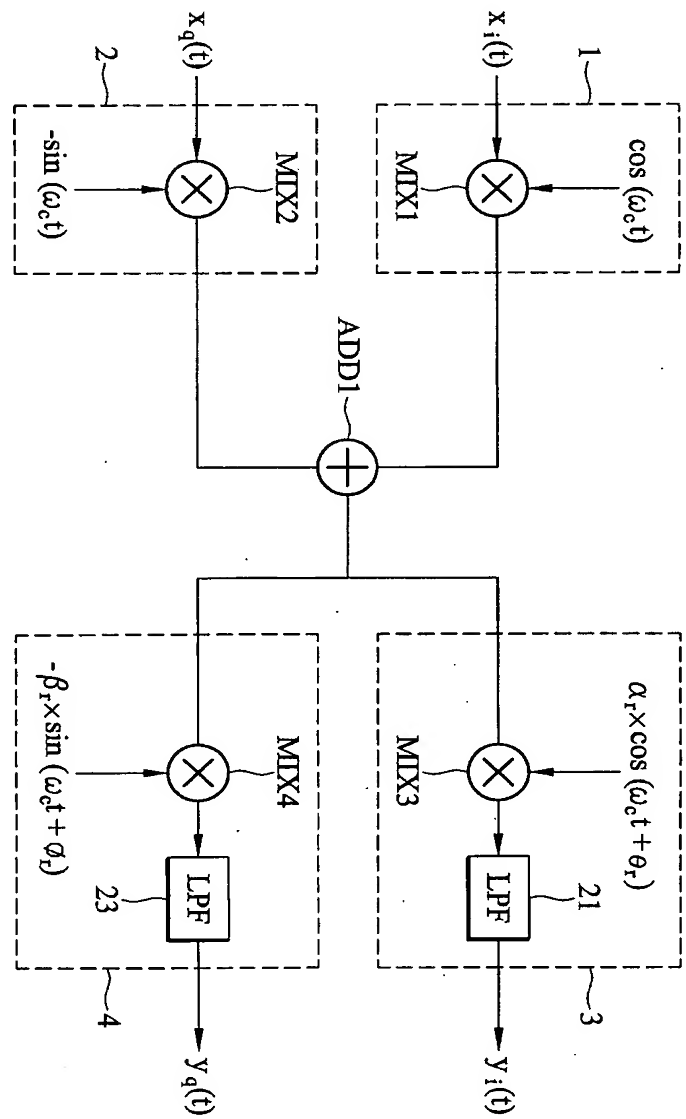
45. The apparatus of claim 40, wherein the amplitude of the real and the imaginary part of the first and second signals are either +1 or -1.

46. The apparatus of claim 1, wherein the first and second signals are independent each other.

47. The apparatus of claim 39, wherein the predetermined signals comprise a third signal and a fourth signal, and the third and fourth signals are symmetric in frequency domain.

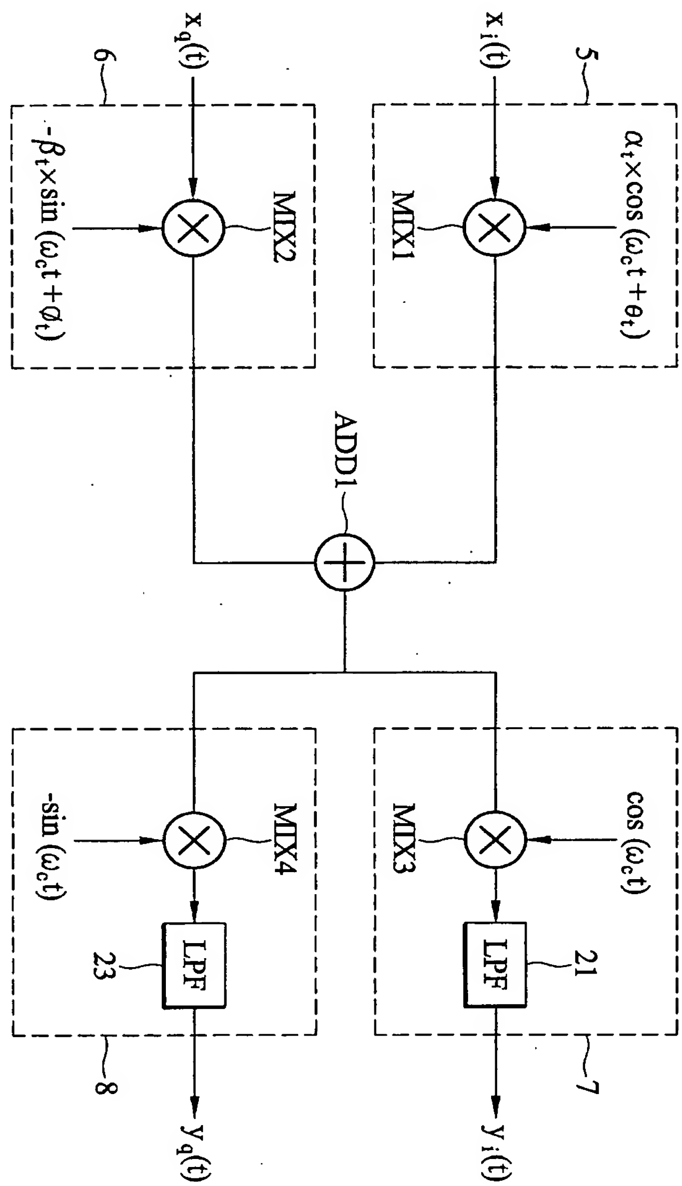
48. The apparatus of claim 47, wherein the real and the imaginary part of the third and the fourth signals are symmetric in frequency domain.

49. The apparatus of claim 48, wherein amplitudes of the real and imaginary part of the third and the fourth signals are the same in frequency domain.



$$\begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix} = \begin{bmatrix} \alpha_r \cdot \cos\theta_r & \alpha_r \cdot \sin\theta_r \\ -\beta_r \cdot \sin\phi_r & \beta_r \cdot \cos\phi_r \end{bmatrix} \cdot \begin{bmatrix} x_i(t) \\ x_q(t) \end{bmatrix}$$

FIG. 1A



$$\begin{bmatrix} y_i(t) \\ y_q(t) \end{bmatrix} = \begin{bmatrix} \alpha_t \cdot \cos\theta_t & -\beta_t \cdot \sin\phi_t \\ \alpha_t \cdot \sin\theta_t & \beta_t \cdot \cos\phi_t \end{bmatrix} \cdot \begin{bmatrix} x_i(t) \\ x_q(t) \end{bmatrix}$$

FIG. 1B

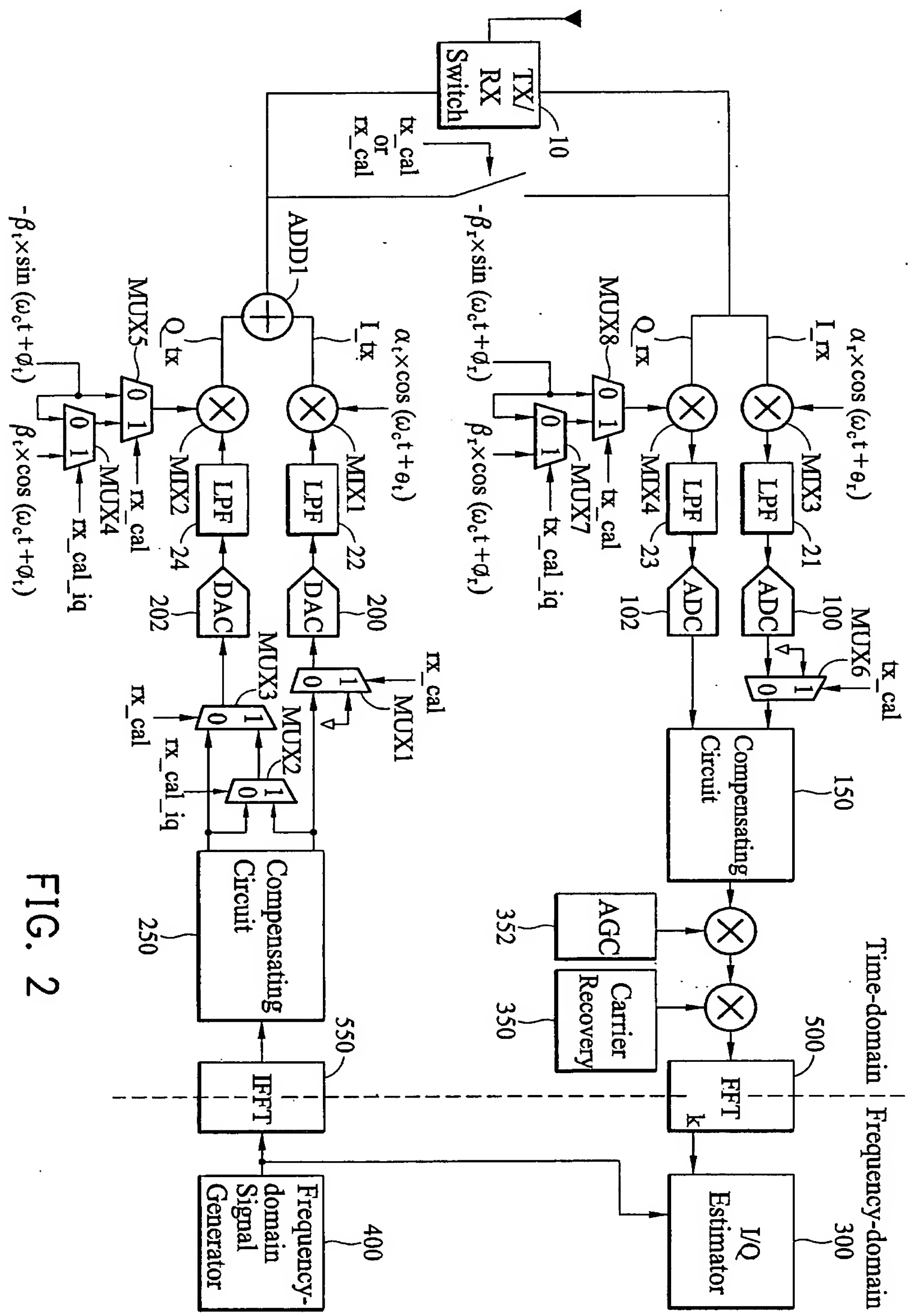
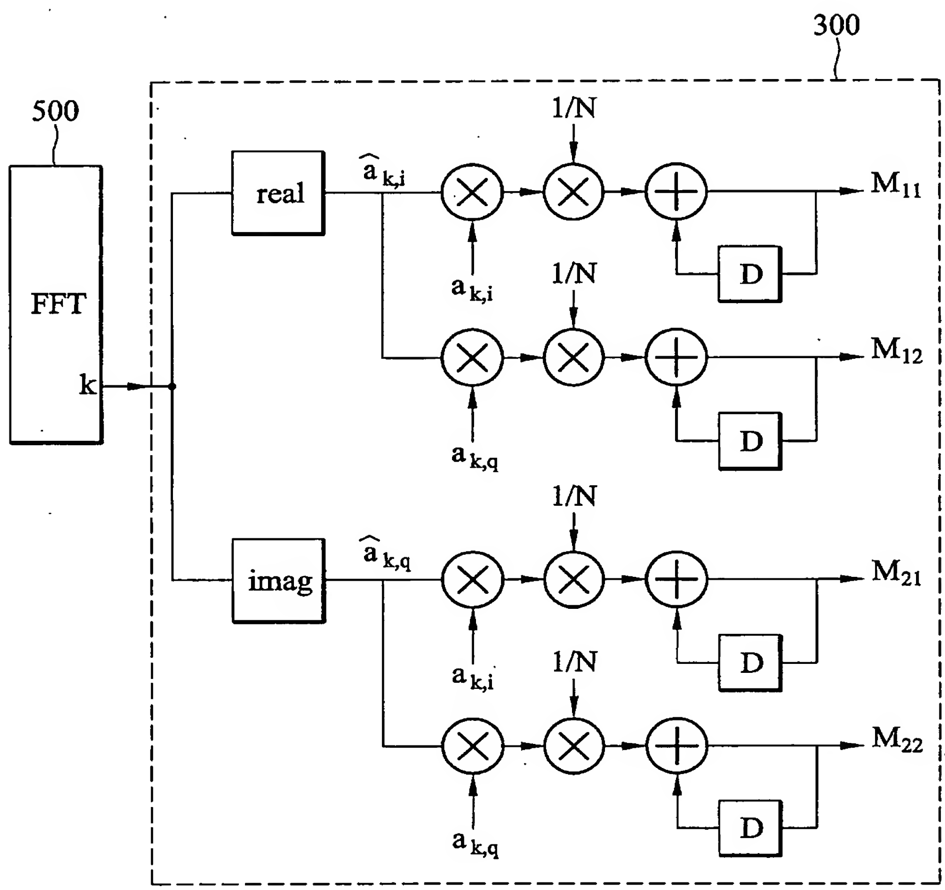

TX/
RX
Switch
10
tx_cal
or
rx_cal
ADD1
MUX8
MUX7
MUX6
MUX5
MUX4
MUX3
MUX2
MUX1
MIX1
MIX2
MIX3
MIX4
I_rx
Q_rx
I_tx
Q_tx
LPF
21
22
23
24
ADC
100
102
DAC
200
202
tx_cal
rx_cal
rx_cal_iq
tx_cal_iq
Compensating
Circuit
150
250
AGC
352
Carrier
Recovery
350
FFT
k
500
IFFT
550
I/Q
Estimator
300
Frequency-
domain
Signal
Generator
400
Time-domain
Frequency-domain

FIG. 2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500
FFT
k
real
imag
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$\hat{a}_{k,q}$
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1/N
1/N
1/N
$a_{k,i}$
$a_{k,q}$
$a_{k,i}$
$a_{k,q}$
D
D
D
D
M_{11}
M_{12}
M_{21}
M_{22}

FIG. 3

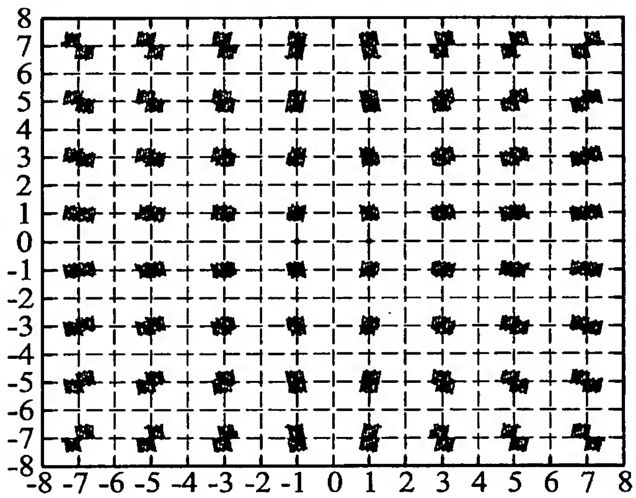
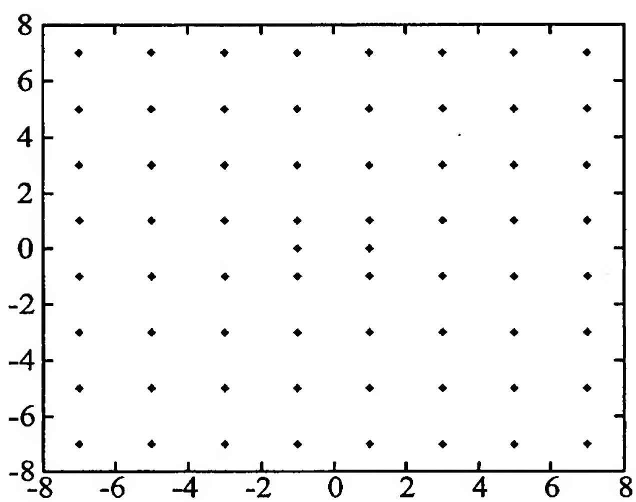

8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

FIG. 4A


8
6
4
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0
-2
-4
-6
-8
-8 -6 -4 -2 0 2 4 6 8

FIG. 4B